FINAL SUMMARY REPORT

An Experimental Study of the Cryoentrainment Pump and the Behavior of Nude Ionization Gauges at Low Temperature

J. A. Daggerhart

Department of Mechanical and Aerospace Engineering

North Carolina State University

Raleigh, North Carolina 27607

May 10, 1972

NASA Grant NGR 34-002-106

TABLE OF CONTENTS

INTRODUCTION

In various uses of vacuum systems, the capability of rapidly obtaining a contamination free vacuum is well recognized. Of the various methods of attaining such a vacuum, the use of the cryopumping technique has been accepted as a promising approach.

However, certain gas constituents present in a typical vacuum system will not be removed by the cryopumping mechanism. For example, helium will not be pumped from the system even if the cryogenic fluid used provides a condenser temperature of 4°K.

From an economic standpoint, the desirability of employing 4°K as a cryopumping temperature may be questionable. The cost of refrigeration equipment increases rather drastically as the operational temperature of a cryopump system decreases below 77°K. For this reason, interest has been stimulated in the use of a condensing temperature of 77°K.

Even though this temperature may be desirable from a purely economic consideration, the application of such a concept is not without its difficulties. For example, of those gases that are normally present in an initially air filled vacuum system, only carbon dioxide and water vapor will be effectively pumped by a 77°K surface. Therefore, to provide a reasonably clean, low-pressure system, the normal cryopumping mechanism cannot be relied upon as the sole pumping method.

In order to circumvent this restriction on the types of gases that are pumped at this temperature, it has been postulated that a gas which is easily condensable at 77°K, be injected into the system in the form of a directed stream. This stream would then entrain the normally non-condensable species by a momentum transfer mechanism. After sweeping through the volume to be pumped, the injected gas stream would then be condensed on a cryopumping surface maintained at 77°K.

Thus, the non-condensable species previously entrained are trapped in the condensate of the injected gas stream. As a result, if the vapor pressure of the condensing gas stream is sufficiently low at 77°K, the entrainment and trapping action will function effectively as a cryo-entrainment pump.

Based on the desired operating characteristics of such a device, certain properties of the injected, or pumping, gas stream may be specified, such as:

(1) an extremely low vapor pressure at 77°K,

(2) low toxic effects,

(3) a high molecular weight to provide entrainment efficiency,

(4) a condensate impermeable to the trapped non-condensable molecules, and

(5) a high thermal conductivity of the condensate to permit large frost buildups on the condensing surfaces.

As a result of these requirements coupled with a desire to easily obtain large quantities of the pumping gas, a commercially available fluorocarbon was selected. Octofluorocyclobutane (C_4F_8), with a molecular weight of 200 was chosen as the primary test pumping gas.

A concurrent effort was also carried out to examine the operating characteristics of nude ionization gauges operating in a low-temperature, low-pressure environment. This effort resulted from certain anomalous effects noted in the operation of ionization gauges during the course of a study of the thermal transpiration effect.

The so-called thermal transpiration effect arises when a pressure sensor is attached to a pressure source by means of a tube in which free molecular conditions prevail and the source and sensor are at different temperatures. Theoretical considerations of the particle number flux from both the warm and cold ends of the tube indicate that the cold end number density should be higher than that at the warm end. This condition arises as a result of the equilibrium requirement that the particle be the same in each direction.

In particular, the equilibrium condition may be expressed as:

$$\frac{N_c}{N_h} = \left[\frac{T_h}{T_c}\right]^{1/2}$$

where, N_c = tube cold end number density

N_h = tube warm end number density

T_c = tube cold end temperature

T_h = tube warm end temperature.

In the particular thermal transpiration studies in question, the temperatures employed were 300°K and 77°K, giving a theoretical ratio of N_c/N_h = 1.97. Since the operational method of an ionization gauge renders it sensitive to number density, it was felt that the "cold gauge" would consistently yield a higher indication than the "warm gauge".

During the course of the investigation, however, the opposite result was noted. For certain conditions of system temperatures and pressures the indication of the gauge exposed to the cold environment was as much as 100 times lower than the gauge exposed to the 300°K temperature.

After eliminating such causes as current leakage and cold wall helium pumping as not being large enough to distort the expected results to such an extent, an experimental program was begun to at least map, if not explain, the gauge behavior in a cold environment.

EXPERIMENTAL PROGRAM

Cryoentrainment Pump Studies

The basic goal in the design of the cryoentrainment system was to provide an accelerated jet of the pumping gas which would sweep the non-condensable gases from a volume and then penetrate a large surface area condenser. To achieve this goal, the experimental apparatus shown in Figure 1 was constructed.

To provide an outer shield volume for the cryoentrainment system, two structures were fabricated from stainless steel and were capable of being isolated from each other.

The outer structure, or shield volume, is in the form of a bell jar 1.32 m in diameter and 1.73 m in height.

The inner structure, comprising the actual cryoentrainment pump, is initially conical in shape to match the 15° half angle of the nozzle used to accelerate the pumping gas from the stagnation chamber. The lower section of the cryoentrainment system is cylindrical in shape and contains the condenser array. A net pumping volume of 900 liters is contained by the structure.

Two condenser arrays were fabricated for useage in the cryoentrainment system. The initial system was formed from one-half inch copper tubing wound into the form of concentric circular cylinders. Four cylinders were used with diameters of 20.3, 40.6, 60.0, and 81.2 cm to give a total condensing surface of 11.62 sq m. The final condenser had a height of 91.5 cm and was mounted with its axis vertical and aligned with the axis of the injection nozzle. The alignment of the two axes insures that the pumping gas is initially directed to the condensing surface and increases the probability of rapid condensation of both the pumping gas as well as the entrained gases.

The pumping system provided to initially evacuate the entire structure from atmospheric pressure consists of a 10 and 16 inch oil diffusion pump in parallel with the entire system and backed by a 50 cfm mechanical pump. The necessity of two oil diffusion pumps to reach system base pressures in the region of 10^{-7} to 10^{-6} torr was created by two factors. The first of these was the large outgassing load imposed on the system by the electric motor used to drive the remotely operable valve on the inner structure. The motor used for this purpose was an off-the-shelf item with no additional steps being taken to adapt it to vacuum service. The second factor reducing the pumping speed was the partial blockage of one of the pump ports by the inner structure itself.

To use the inner structure in the cryoentrainment mode after the initial pumpdown, the remotely operated valve is employed to isolate this structure from the shield volume and the auxiliary pumping system. In this way, it is insured that any observed pumping action in the inner structure is attributable to the cryoentrainment action and not to the secondary pumping system.

To begin a typical test cycle, the entire system is initially evacuated to a pressure near 10^{-6} torr. This initial pumpdown is carried out with no cryogenic fluid in the condenser. As a result of this procedure, it is insured that the condenser is not contaminated with large quantities of condensate (such as carbon dioxide and water vapor) prior to its usage as a cryoentrainment system.

Upon completion of the condenser cooldown with liquid nitrogen, helium is introduced to the test volume to provide the non-condensable gas to be pumped. To insure that the gas contained in the test volume is predominately non-condensable, the initial base pressure is raised at least two orders of magnitude by the introduction of helium.

After establishing the desired pressure level in the system, the inner structure is isolated and the pumping gas is admitted to the system through the expansion nozzle.

In order to monitor the variation of the helium partial pressure, as a function of time after the injection of the entrainment fluid, a partial pressure analyzer was located on the inner structure. This gauge is capable of sensing both system total pressures - to a maximum of 10^{-5} torr and partial pressures for species with mass numbers of 70 and below. To increase the total pressure range to 1 torr, a high pressure ionization gauge was employed in conjunction with the partial pressure analyzer.

In planning the operational mode of the cryoentrainment system, two avenues were open with respect to the method of introducing the pumping gas. The foreign gas stream may either be admitted in short bursts or continuously.

The short burst method is favored for several reasons. For a given pressure ratio between the stagnation chamber and pump volume, a certain exhaust velocity will be imparted to the pumping fluid as it is accelerated through the nozzle. It is reasonable to assume that, in a continuous injection, the pressure in the pump volume will be elevated as the injection process is begun. This should occur since instantaneous condensation of all the injected mass will not take place.

On the other hand, it is to be expected that the background pressure will drop in the short burst method as condensation occurs in the time interval between bursts of the pumping fluid. Thus, for the periodic burst technique, a higher pressure ratio should be available for accelerating the pumping fluid than for a continuous injection of the entrainment gas.

Two further disadvantages of the continuous method that may be cited are the consumption of entrainment fluid and the degradation of the condenser performance as a result of condensate build-up.

Due to these considerations, the short burst technique was selected as the operating mode of the cryoentrainment system.

To provide for the introduction of known quantities of the pumping fluid into the pump volume, a small volume was attached to the stagnation chamber. This volume may be charged to a known pressure and is separated from the pump volume by a solenoid valve which is triggered by an external timer circuit. The use of a timed cycle permits the introduction of a known mass of pumping fluid which is repeatable to an extent not possible by manual operation of the injection cycle.

Nude Ionization Gauge Characteristics

To examine the characteristics of nude ionization gauges exposed to a low temperature environment, the system shown schematically in Figure 2 was employed.

The main experimental system consists of two ten liter stainless steel vessels. The vessels are interconnected by a 3 mm I.D. capillary tube which is 48 cm in length. Each vessel has provisions for mounting two nude ionization gauges and has the capability of being baked to 400°C.

To provide a leak free environment, all joints in the system are heli-arc welded and any penetrations in the vessels are sealed with metal gasketed flanges. In evaluating the integrity of the vacuum system, leakage/desorption rate tests - carried out at 3.5×10^{-5} torr and extending over a week in time - have consistently yielded a value of 2.1×10^{-9} torr-liters/sec.

To begin a particular experimental run, the system was baked to a temperature of 400°C for a period of 24 hours at an ionization gauge indication of 10^{-5} torr. After completion of the bake-out period, the vacuum valves were sealed and the vessels allowed to cool to room temperature.

Helium is utilized as the test gas to insure that the background gas in the system is non-condensable at the test temperature of 77°K. In this way any variations in the indication of the gauge exposed to the test temperature will not be due to cold wall adsorption.

After the system bake-out has been completed, the experimental procedure is to admit helium through a cold trap system so as to raise the system pressure by at least two decades. The valves are then resealed and the pressure is allowed to reach an equilibrium condition. Following the establishment of equilibrium, liquid nitrogen is added to the dewar surrounding one vessel and the variation of the system pressure as a function of time is monitored.

The basic system is arranged so that the vessel mounted in the liquid nitrogen dewar may either be isolated from or operated in conjunction with the room temperature vessel by means of the capillary connection. When using a single isolated vessel, the indication of the gauge should not vary regardless of whether or not liquid nitrogen is present in the dewar. This results from the basic operating principle of an ionization gauge in which it is sensitive to particle number density and not system pressure.

In using the interconnected vessel system, the indication of the room temperature (300°K) gauge is used as a check on that of the gauge exposed to the 77°K surface. With this situation, the thermal transpiration effect should dominate the system and the 77°K vessel gauge indication should be $\left[T_R/T_c\right]^{1/2}$ times that in the 300°K vessel.

DISCUSSION OF RESULTS

Cryoentrainment Pump Studies

The earliest experimental method of beginning a series of runs, after the initial pumpdown of the system, was to fill the condenser until liquid nitrogen was vented from the system for approximately thirty minutes. At this time, the liquid supply was cut off and the condenser was then periodically supplied with liquid nitrogen during the course of an experimental run.

Following the filling of the system with helium and the isolation from the shield volume, the pumping gas was admitted to the entrainment pump in short bursts. Typical data resulting from such a technique are shown in Figure 3. In each of the four injections, the pumping gas is octofluorocyclobutane (C_4F_8) at a stagnation pressure of 25 psig which corresponds to an injected mass of 4.8×10^{-2} grams.

In the time interval between each injection, the inner system was kept sealed and no new helium was added. In other words, injection 1 was made into an essentially pure helium environment. Following the stabilization of the internal pressures, the second injection was made.

Thus, the second injection was made into a volume in which a mixture of helium and the C_4F_8 remaining from the previous injection was present. Injections 3 and 4 followed in the same manner.

It may be seen from the figure that a minimum value of 3×10^{-6} torr occurs for each injection. A rapid release of the helium trapped in the cryodeposit is also evident with the helium partial pressure returning to near its original value prior to the injection.

For each injection shown in Figure 3, the minimum value of the helium partial pressure is reached approximately three seconds after the admission of the pumping fluid. The pumping speeds -- based on this three second interval -- and the desorption rates of the helium from the cryodeposit -- based on a two minute time interval from injection -- are summarized in Table 1 for each of the four injections.

TABLE 1

Summary of Pumping Speed and Desorption Rates With C_4F_8 at 25 psig

Injection Number	Pumping Speed liters/sec	Desorption Rate torr-liters/sec(x 10^5)
1	780	9.68
2	732	6.07
3	687	3
4	516	8.46

In order to improve the retention of the helium trapped in the cryodeposit, the experimental procedure was modified so that liquid nitrogen flowed freely from the vent line during the course of any particular run. The data shown in Figure 4 were obtained by this technique.

The initial time variation of the helium partial pressure is similar to that obtained by the prior technique in that a rapid decrease to a minimum value is observed immediately following injection. The most significant difference occurs in the time period exceeding one minute after injection.

The release of the trapped helium into the pump volume is reduced such that the helium partial pressure is essentially constant with time. It is also noted that each successive injection of C_4F_8 does lower the helium partial pressure with respect to that which existed prior to the injection. The pumping speeds, again based on the three second interval after injection and the simple exponential variation of pressure with time, are summarized in Table 2.

TABLE 2

Summary of Pumping Speeds with C_4F_8 at 25 psig

Injection Number	Pumping Speed liters/sec
1	759
2	85.8
3	31.5
4	25

The decrease of the initial pumping speed with increasing numbers of injections, as noted in Tables 1 and 2, is typical of the operating characteristics of the cryoentrainment pump. This effect is related to the presence of uncondensed pumping fluid in the pump volume as well as the increase of the helium molecular mean free path with each injection.

When a gas stream passes through a stationary target gas, the probability of collision between the two types of molecules is inversely proportional to the mean free path of the target gas. Thus, for an injection into an initially pure helium environment, as for injection 1 in Table 2, at a relatively high helium pressure, it is to be expected that the effective pumping speed will be high.

For the second and following injections, the helium partial pressure has been reduced, thereby increasing the helium mean free path length. As a result, the collisional probability decreases; with a subsequent fall in the effective pumping speed of the system.

A second factor that enters into the reduction of the pumping speed of the system is the presence of uncondensed pumping gas molecules from previous injections. For the second and following injections, the momentum transfer, or entrainment, mechanism is divided between the helium molecules and the entrainment fluid previously injected but not yet condensed. The pumping speed of the unit is then expected to be continually reduced with each injection.

Further examinations with C_4F_8 were carried out using a lowered stagnation pressure. In combination with this, a 50 cfm mechanical pump was attached to the condenser vent line to lower the condenser internal pressure, thereby lowering the condenser temperature.

Typical data resulting from an injection pressure of 380 torr is shown in Figure 5. The expected rapid decrease of the helium partial pressure is readily apparent following the injection of the C_4F_8. This initial pressure drop, over the three second interval following the injection, corresponds to a helium pumping speed of 1500 liters/sec.

This pumping speed, requiring an injected mass of 8.9×10^{-3} grams, is to be contrasted with the results tabulated in Tables 1 and 2 which indicate maximum speeds of 780 and 759 liters/sec, respectively. This indicates that even very small quantities of the pumping fluid may be used effectively when the condenser is well cooled.

A second feature to be noted from Figure 5, is the variation of the helium partial pressure with time following the injection. A slow rise in the helium partial pressure is initially noted which corresponds to a desorption rate of 7.5×10^{-8} torr-liters/sec. In the time period beyond this initial phase, the rise in the partial pressure is too small to be measured. Although not indicated in these data, the trapped helium is normally held in the cryodeposit for periods in excess of one hour. The desorption rates for these longer times are typically on the order of 1.5×10^{-8} torr-liters/sec.

Further injections of C_4F_8 did not appreciably lower the helium partial pressure. Since the first injection removed the majority of the helium present in the system, the efficiency of the second injection must be reduced as a result of the much lowered collisional probabilities.

Carbon dioxide was also employed to examine the effects of a variation in the molecular weight of the pumping medium. Typical results of such a pumping cycle are shown in Figure 6.

The response of the cryoentrainment pump using carbon dioxide is qualitatively the same as that found when using C_4F_8. The initial injection into the system yielded a helium pumping speed of 830 liters/sec as compared with the 1500 liter/sec value found with C_4F_8. Thus, as would be expected, a reduction in the molecular weight of the pumping fluid is accompanied by a reduction in the effective pumping speed of the system.

For the second injection, the pumping speed is reduced to 8.75 liters/sec and finally decreased to 6.6 liters/sec for the third injection. Again, this is attributable to the reduction in the collisional probabilities following each injection as well as the presence of uncondensed carbon dioxide.

The pumping speed of the cryoentrainment pump is also a function of the injection pressure as well as the molecular weight of the pumping medium. As an example of this, a pumping speed of only 52.2 liters/sec was obtained following an injection of C_4F_8 at a stagnation pressure of 250 torr. This value is to be compared with the previously quoted value of 1500 liters/sec obtained with a stagnation pressure of 380 torr.

Along with the ability of the cryoentrainment pump to remove system constituents normally non-condensable at 77°K, the ability to effectively remove the injected pumping gas must be considered.

The variation in the system total pressure indication is shown in Figures 7 and 8 following injections of carbon dioxide and C_4F_8. It is apparent from these figures that the system pressure is generally increased with each injection; a characteristic obviously not desirable in a vacuum pump. The pressure data for the carbon dioxide injections indicates that the surface temperature of the condensate is in the neighborhood of 105°K rather than the desired value of 77°K. Since the conditions in the vacuum system are below the triple point for carbon dioxide, it was felt that a porous cryodeposit was formed with poor heat transfer characteristics.

Although vapor pressure-temperature data were not available for the C_4F_8, it was assumed that a similar deposit was formed with a resultant high surface temperature.

A second small system was constructed to allow the visual observation of the types of cryodeposits formed. Viewing ports were provided to monitor the formation of the cryodeposit formed on a stainless steel surface maintained at 77°K.

Upon bleeding C_4F_8 into the system, it was found that the deposit did appear to be very porous and could, in fact, be dislodged by vibration. These observations tend to substantiate the existence of a high condensate surface temperature in the cryoentrainment system with a resultant high vapor pressure. A further contributor to the high background pressure, as seen in Figure 7, was found to be due to the flaking off of the condensate under the action of vibration and re-entering the system through evaporation.

In an attempt to provide an operational pressure level of 10^{-10} torr for the entrainment system, a new condenser unit was designed and fabricated.

For construction of the new condenser unit, commercially available finned copper tubing was used in order to provide a greatly increased area capability in the same volume required by the original condenser. A geometric analysis of the available condensing volume in the cryoentrainment pump indicated that the new condenser could easily be constructed so that the area would be larger than the old unit by a factor of 10. This increase in area should offer a greatly improved level of performance as compared with previous condensing unit.

To prevent blockage of the unit by the accumulation of condensate between the fins, the fin separation was set at 2.54 cm in the upper third of the condensing unit, 1.27 cm in the middle third, and 0.635 cm in the lower third. The decreasing fin spacing was employed to offer increasing resistance to any of the condensate that may become detached from the condensing surface and fall toward the bottom of the condenser. Any of the condensate that is allowed to escape from the condenser will eventually evaporate and reenter the main pumping volume leading to an undesirably high background pressure.

As a further aid to condenser efficiency, a liquid nitrogen shield was constructed to surround the basic condensing unit for the purpose of lowering the radiation heat load. The shield was installed as a liner that was concentric with the outer shell of the cryoentrainment pump and secured to that shell by means of studs penetrating both the shield and the pump outer wall.

At the present time, this condenser unit has not been fully evaluated as a result of the leakage induced by the cyclic pressure and temperature variations.

Nude Ionization Gauge Characteristics

The response of a nude ionization gauge to an extended exposure to a 77°K surface is shown in Figure 9. In this particular figure, the vessels are interconnected by the capillary tube and the indication of both the cold and warm gauges are shown for comparison.

The gauges were operated continuously for a period of five days and liquid nitrogen was kept in the dewar flask except for short periods at night.

It should be noted from the figure that the initial pressure indications in the two vessels were approximately an order of magnitude apart. As the time constant of the capillary tube is 30 minutes, the thermal transpiration effect should shortly dominate the system so that the initial spread in indications should not be considered significant.

It may be observed from the figure that the indication in both vessels continued to decrease with time with that in the hot vessel indicative of a pumping rate of about 10^{-4} liters/sec. For this type run, no lower bound on the pressure indication was found.

With increasing time, the indication in the cold vessel becomes approximately 10^{-2} times that in the warm vessel. From purely theoretical considerations, one would expect that the cold vessel indication would be twice that in the warm vessel.

A second type of test was performed with the vessel immersed in the liquid nitrogen bath completely isolated from the 300°K volume. In this system configuration, the ionization gauge indication should be the same with or without liquid nitrogen in the dewar if the nude gauge truly responds to system density.

The results of this study are shown in Figure 10. It is apparent that if the initial system pressure indication is above 5×10^{-5} torr, the addition of liquid nitrogen causes a decrease in the pressure indication by a factor of approximately two. It should be noted here that the decrease in the pressure indication occurs in the time period that it takes to cool just the bottom portion of the vessel.

For initial system pressure indications below about 10^{-5} torr, the cooling of the bottom of the vessel causes a decrease in the indication by a factor of about 100. It is also seen that the drop in the pressure indication for pressures between the two values is related to the initial value of the system pressure.

To account for this effect, three explanations arise and are:

(1) that the particular gauge unit is itself faulty,

(2) that strong adsorption of the helium molecules or ions is taking place on the cold walls, or

(3) that the actual operation of the gauge unit is being affected in some way by the cold wall.

The first possibility was very simply checked by the use of several different gauge units. In each case the same type of behavior is noted.

The possibility of adsorption of either system contaminants or helium molecules or ions was checked in two ways. As may be seen from Figure 9, the cold indication is consistently below that for the hot vessel for times nearing 10^4 minutes even with the two vessels interconnected.

In the presence of adsorption of any system contaminants, such as carbon dioxide or water vapor, the result should be a net decrease in the system number density. Then, at this new value of the system number density, the thermal transpiration effect should force an equilibrium condition in which the cold gauge indication is twice that of the hot gauge. However, in the data obtained to the present, the gauge mounted in the 300°K vessel indicates, at sufficiently low pressures, a number density in excess of that indicated in the cooled vessel.

A second test of the adsorption characteristics was made by isolating the cooled vessel from the 300°K volume. In this way, the effect of variable cooled area could be examined.

To initiate this series of experiments, the system was baked and the base pressure was raised two decades by the admission of helium. By this technique it was insured that the major system constituent was helium so that adsorption of carbon dioxide and water vapor would not be a factor in the resulting gauge indications.

After the establishment of an equilibrium pressure indication of 5×10^{-6} torr, liquid nitrogen was placed in the dewar so that just the bottom surface of the vessel was cooled. This area amounted to 182 sq cm and was located a distance of 45.7 cm from the gauge structure.

Upon addition of the liquid nitrogen, the final pressure reached was 3×10^{-6} torr. If one now assumes that the gauge indication is in no way affected by the presence of the cold surface, these two gauge indications suggest that 3.5×10^{15} particles have been removed from the system by the cold surface. Taking this in conjunction with the cooled area of 182 sq cm yields a surface coverage of 1.92×10^{13} particles/sq cm.

After equilibrium was established with only the bottom cooled, the liquid nitrogen level was raised 22.9 cm up the vessel wall. This resulted in an additional 1095 sq cm being available as an adsorption site for the helium particles.

If one now assumes that the newly cooled area allows the same site coverage as the original area, an additional 2.05×10^{16} particles should be removed from the system. This would, however, require that more particles be adsorbed than were present in the system at this time.

With cooling of the additional area, the gauge indication only fell to a value of 2.75×10^{-6} torr. This was indicative of an added surface coverage of 3.94×10^{11} particles/sq cm.

Thus it would appear that the extent of the cooled area is not a primary factor, as would be expected if adsorption was the primary driving force in the occurrence of this gauge anomaly. Rather, it would appear that it is merely the presence of the cooled surface area that is the controlling factor.

It should also be noted here that in postulating an adsorption effect and using an ionization gauge for measurement, it is not possible to specify whether helium molecules or ions are being adsorbed.

The third possible explanation for this effect is that the basic operating mode of the ionization gauge is being in some manner influenced by the presence of the cold surface.

At high system pressure levels, the primary mode of molecular interaction will be molecule-molecule collisions. This should result in a tendency toward removing the "memory" of the cold surface prior to the encounter of the molecules with the gauge structure. In other words, at high pressure levels, the effect of the cold surface should be minimized or disappear. Therefore, in the completely isolated vessel, the gauge indication should remain fixed whether the vessel is cooled or not. This tendency is noted experimentally as may be seen in Figure 10.

On the other hand, as the system pressure is lowered, the collision mechanism becomes primarily molecule-wall rather than molecule-molecule.

Thus, more and more molecules will arrive at the gauge structure retaining "memory" of the 77°K surface as the pressure is lowered. Therefore, if the performance characteristics of the ionization gauge are indeed modified by the presence of the cold wall, the effect should become more pronounced as the system pressure is lowered. This is indeed the case as is found experimentally.

In the experimental work performed to the present, the configuration of the apparatus did not allow the exact cause of the observed gauge discrepancy to be defined. The data obtained suggests that the effect may be attributable to a combination of helium cold wall pumping and some as yet undefined effect on the gauge resulting from the proximity of a cold wall. At the present time it is not possible to assign a relative importance to either contributor.

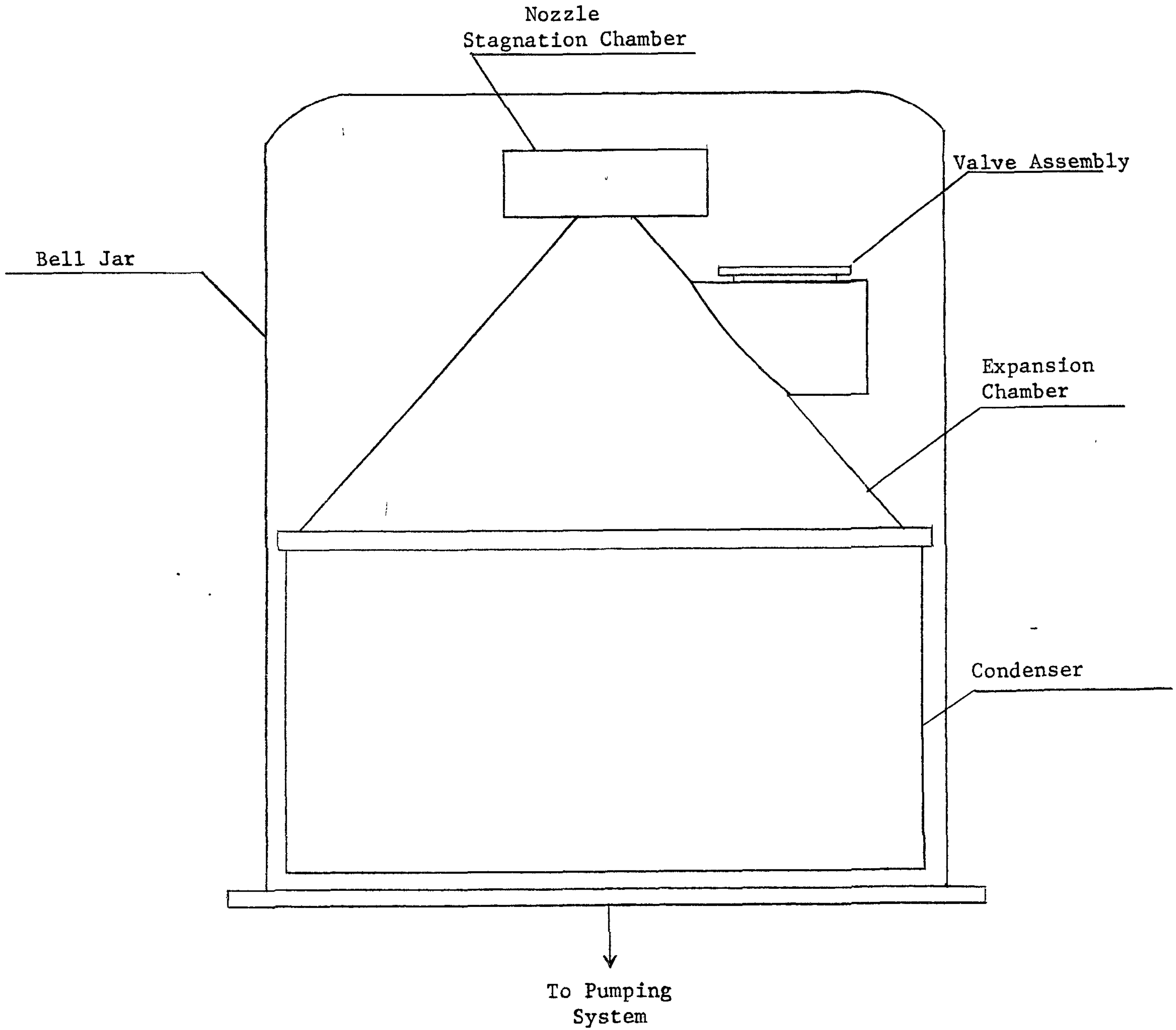

Figure 1. Schematic of the Cryoentrainment Apparatus

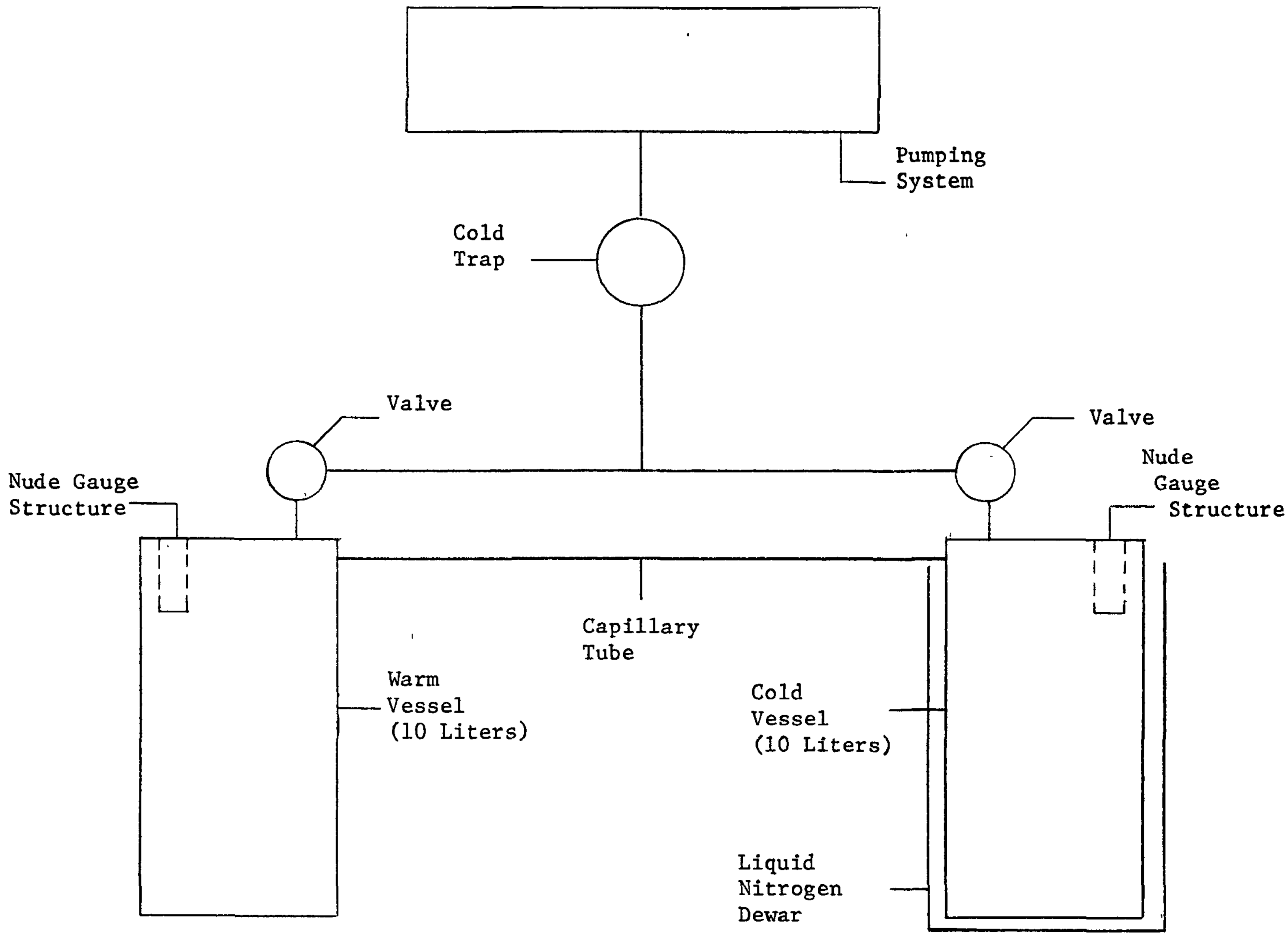

Figure 2. Schematic of ionization gauge performance system

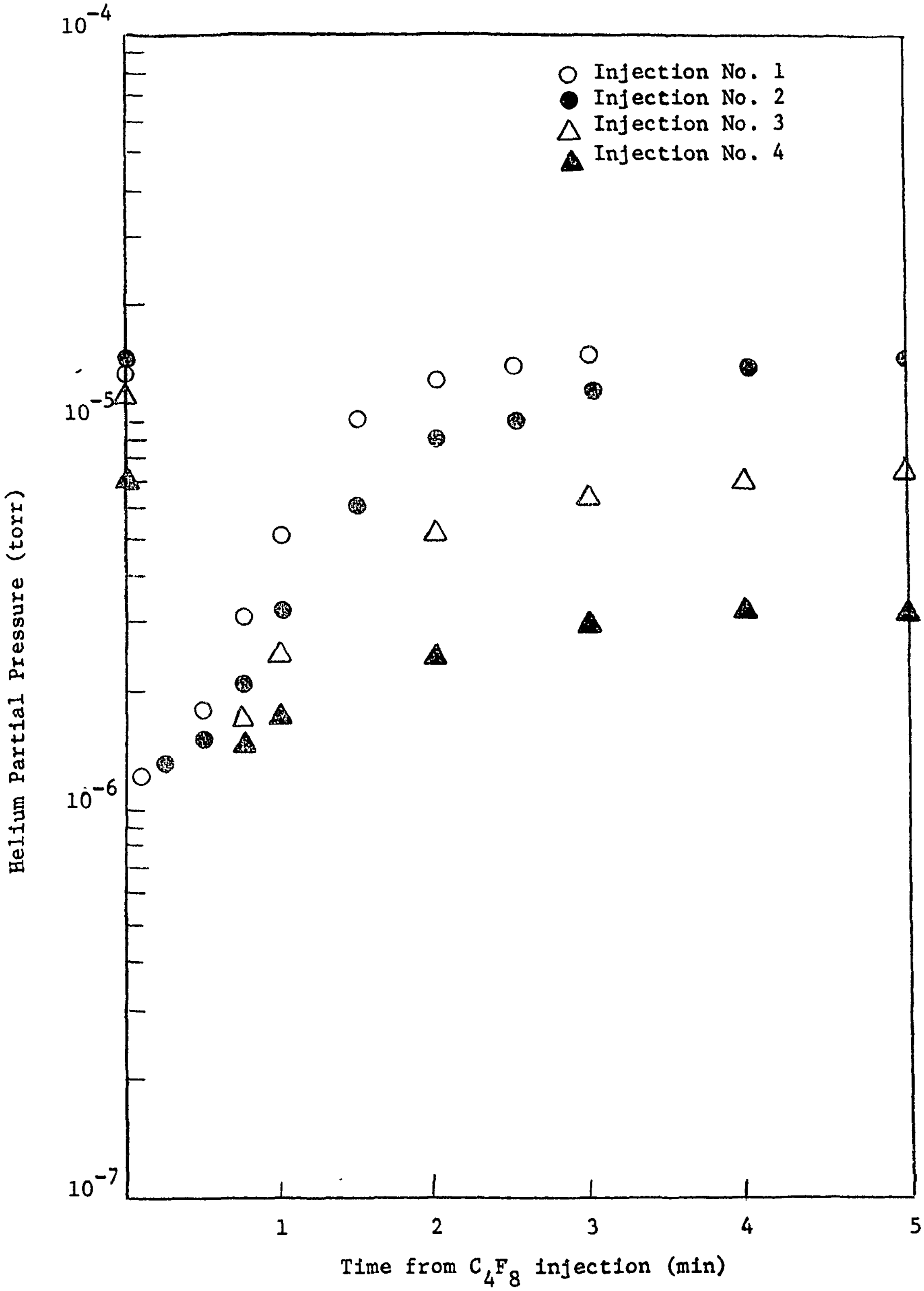

Figure 3. Helium pumping by C_4F_8 injection at 25 psig stagnation pressure

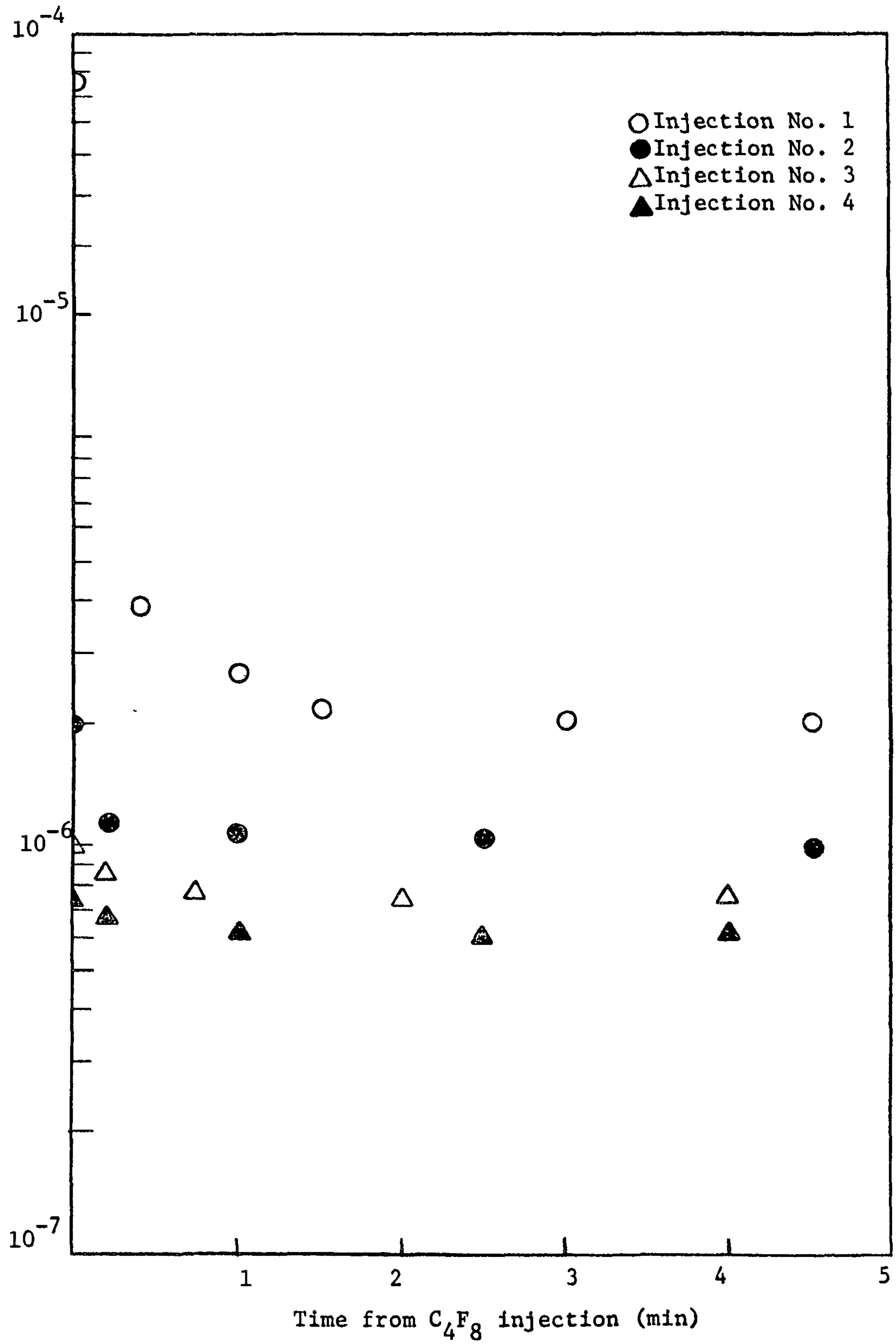

Figure 4. Helium pumping by C_4F_8 injection at 25 psig stagnation pressure

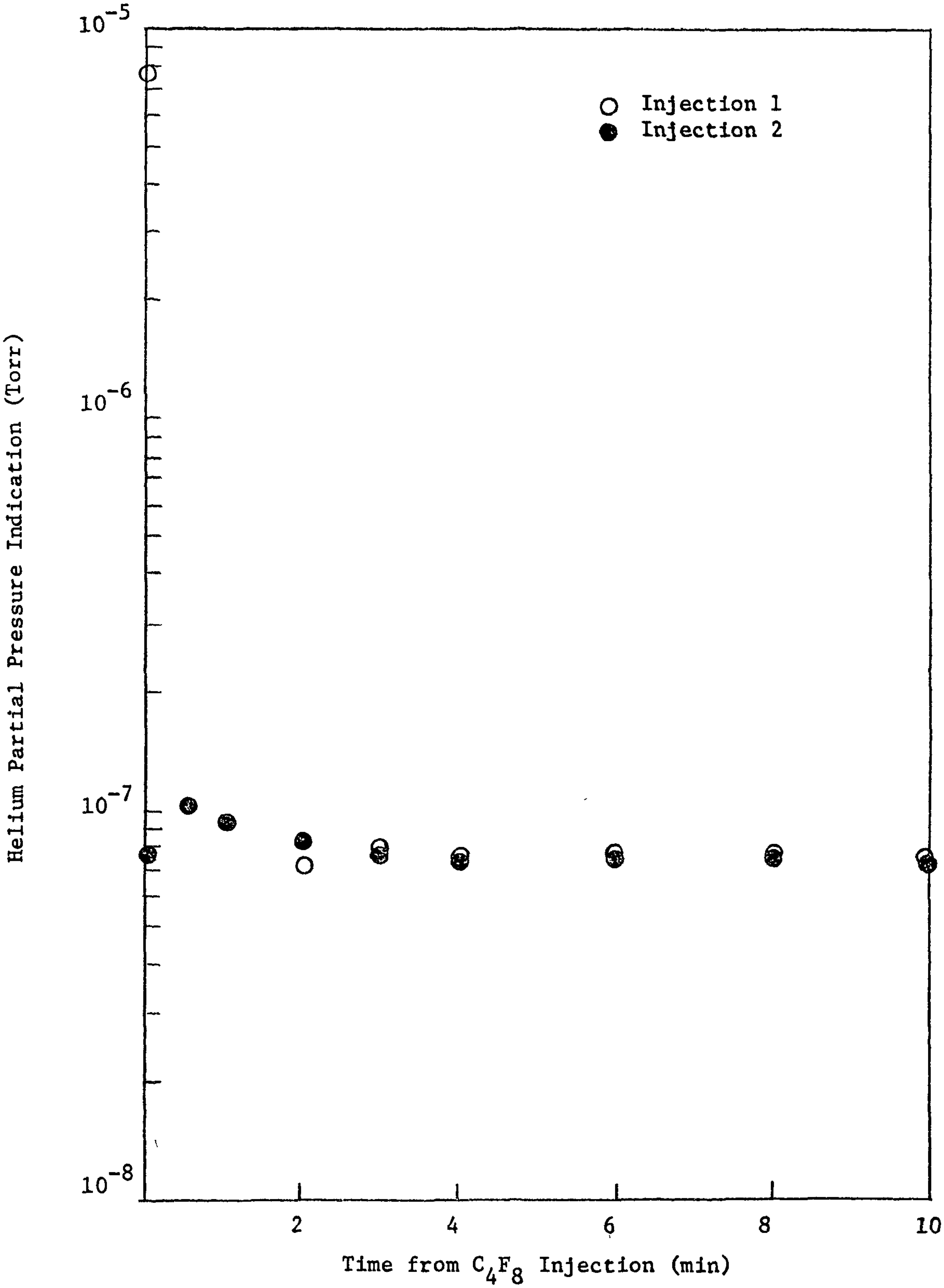

Figure 5. Helium Entrainment by C_4F_8 at 380 torr stagnation pressure

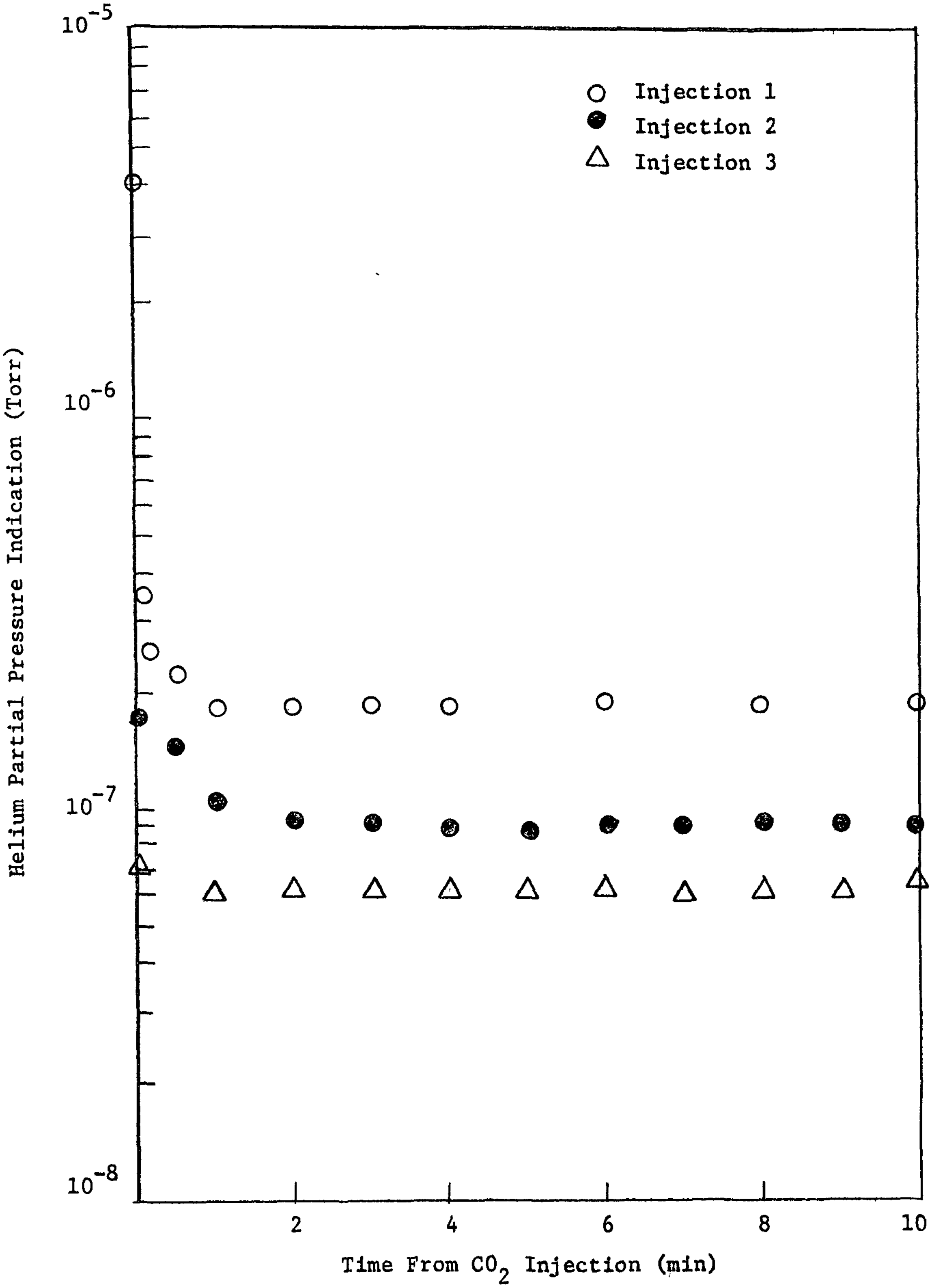

Figure 6. Helium Entrainment by CO_2 at 380 torr Stagnation Pressure

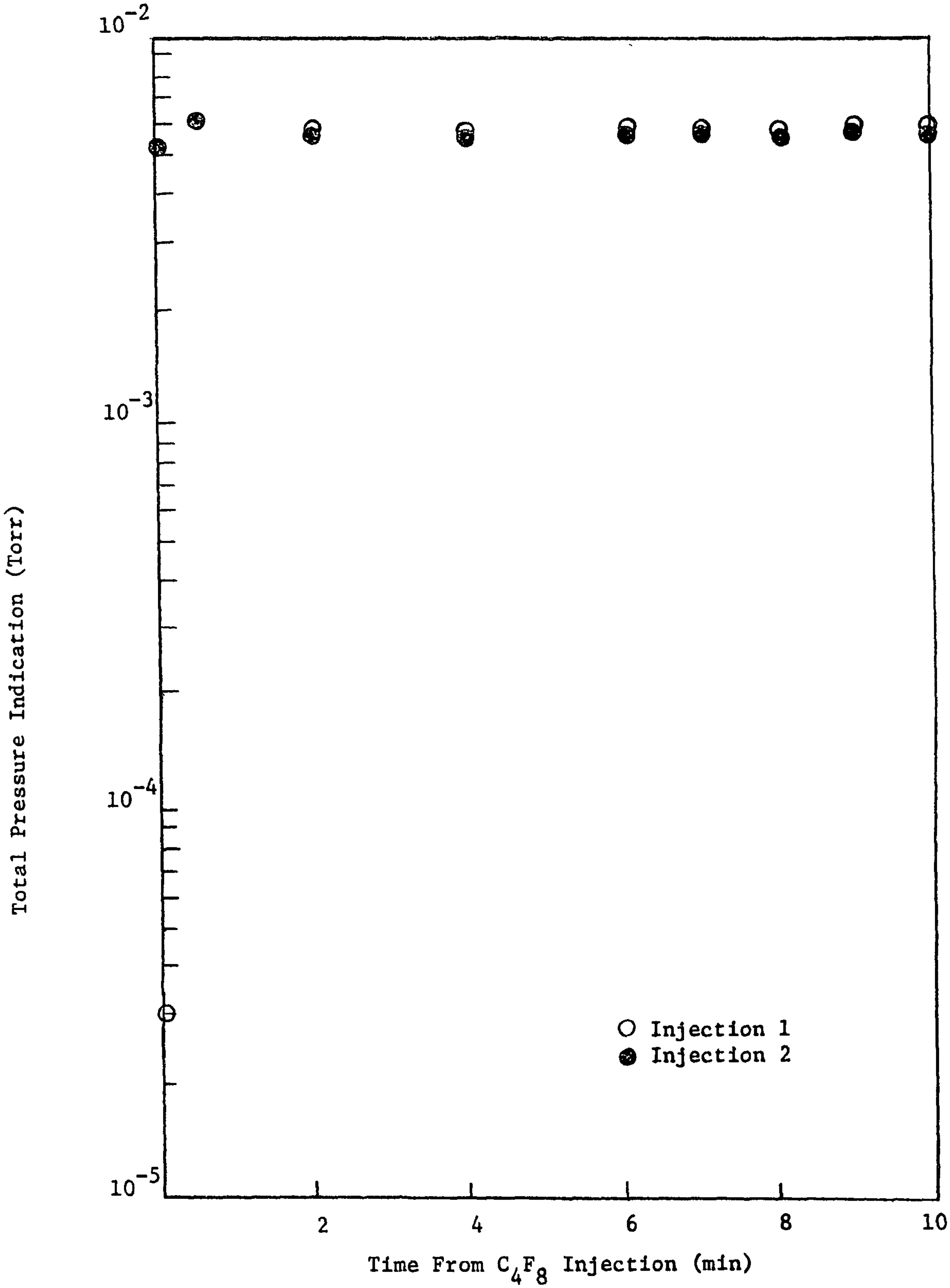

Figure 7. Total Pressure Variation with C_4F_8 Injection at 380 Torr Stagnation Pressure

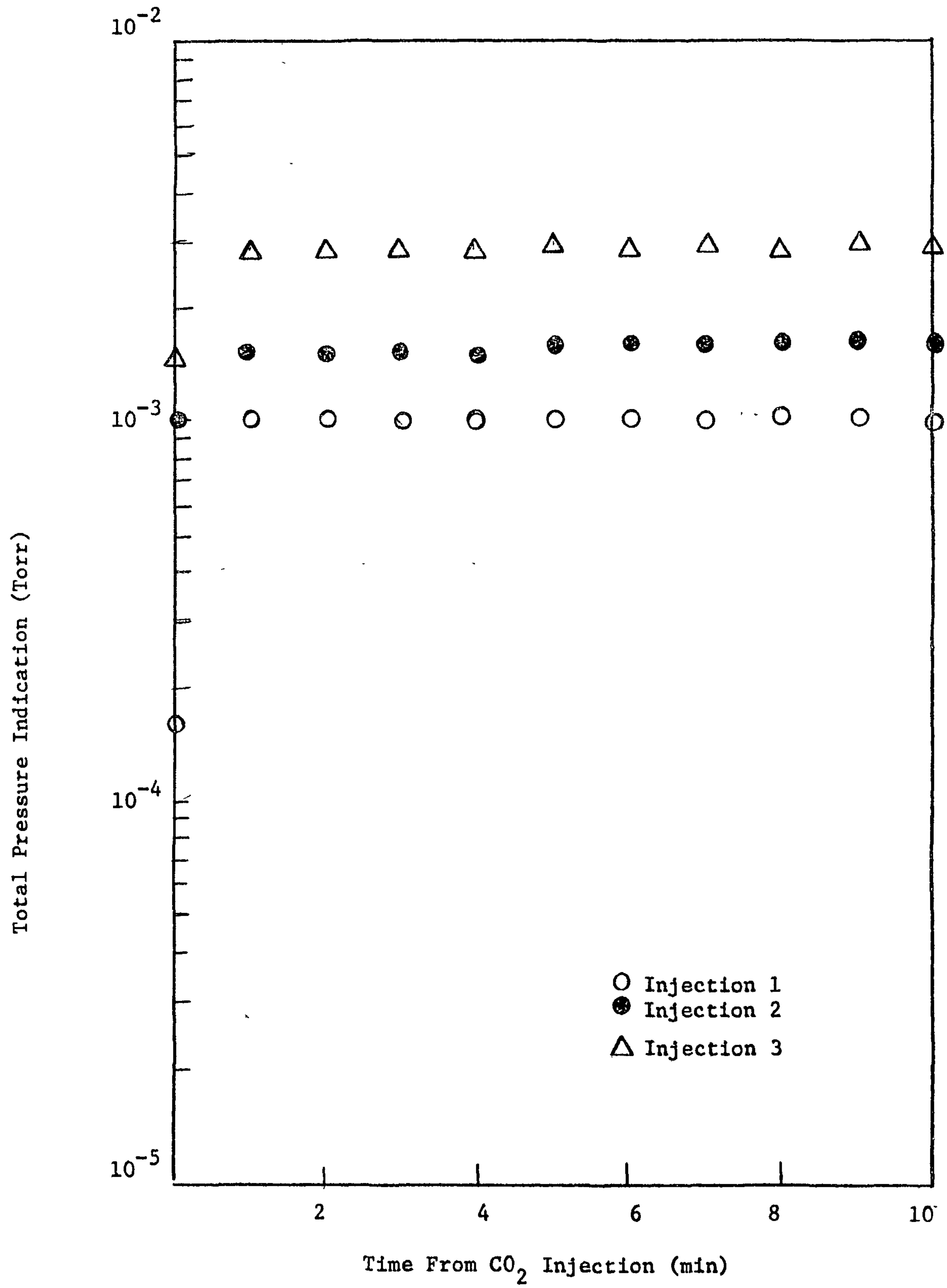

Figure 8. Total Pressure Variation with CO_2 Injection at 380 Torr Stagnation Pressure

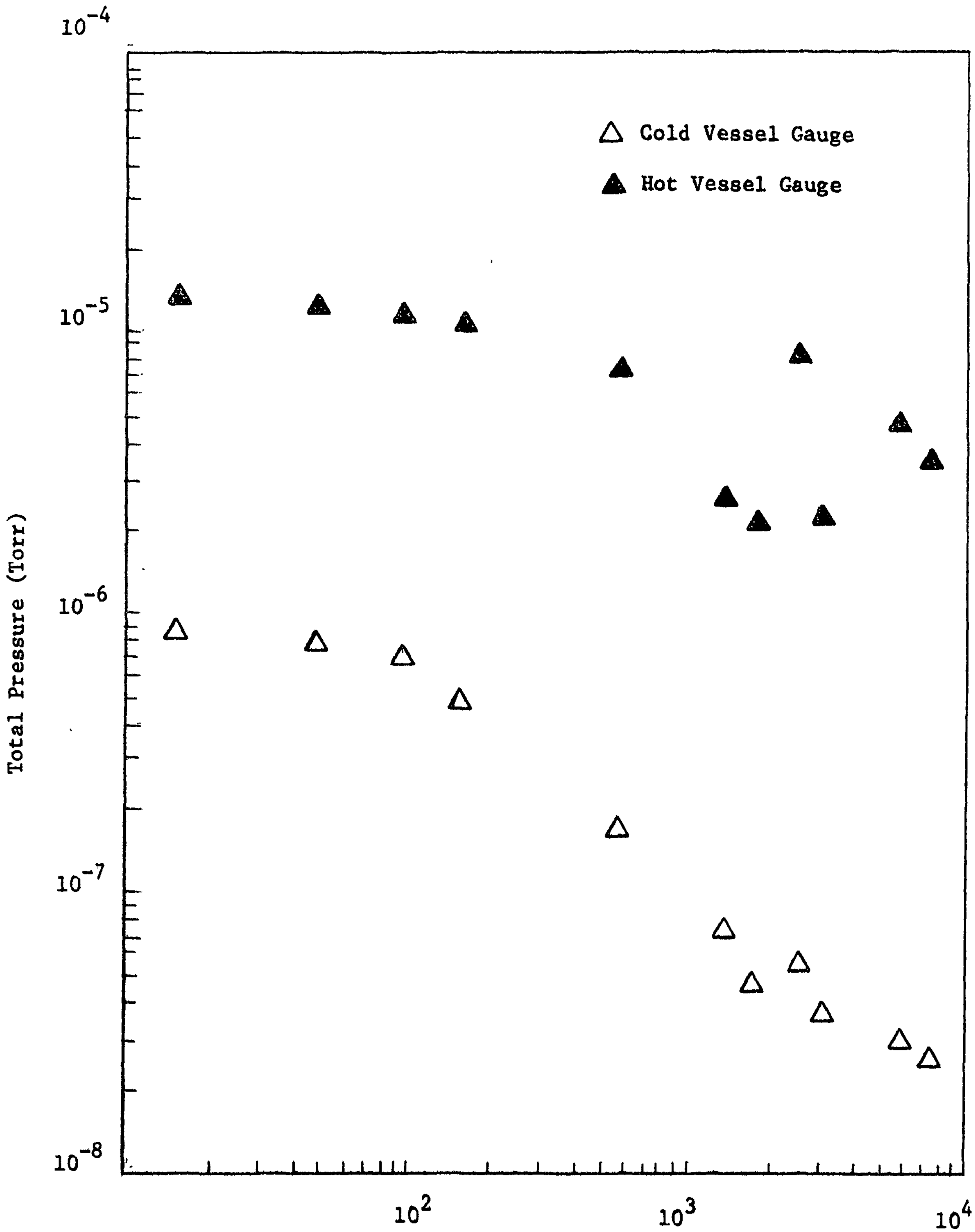

Figure 9. Comparison of indications of ionization gauges in "hot" and "cold" vessels during an extended period of observation.

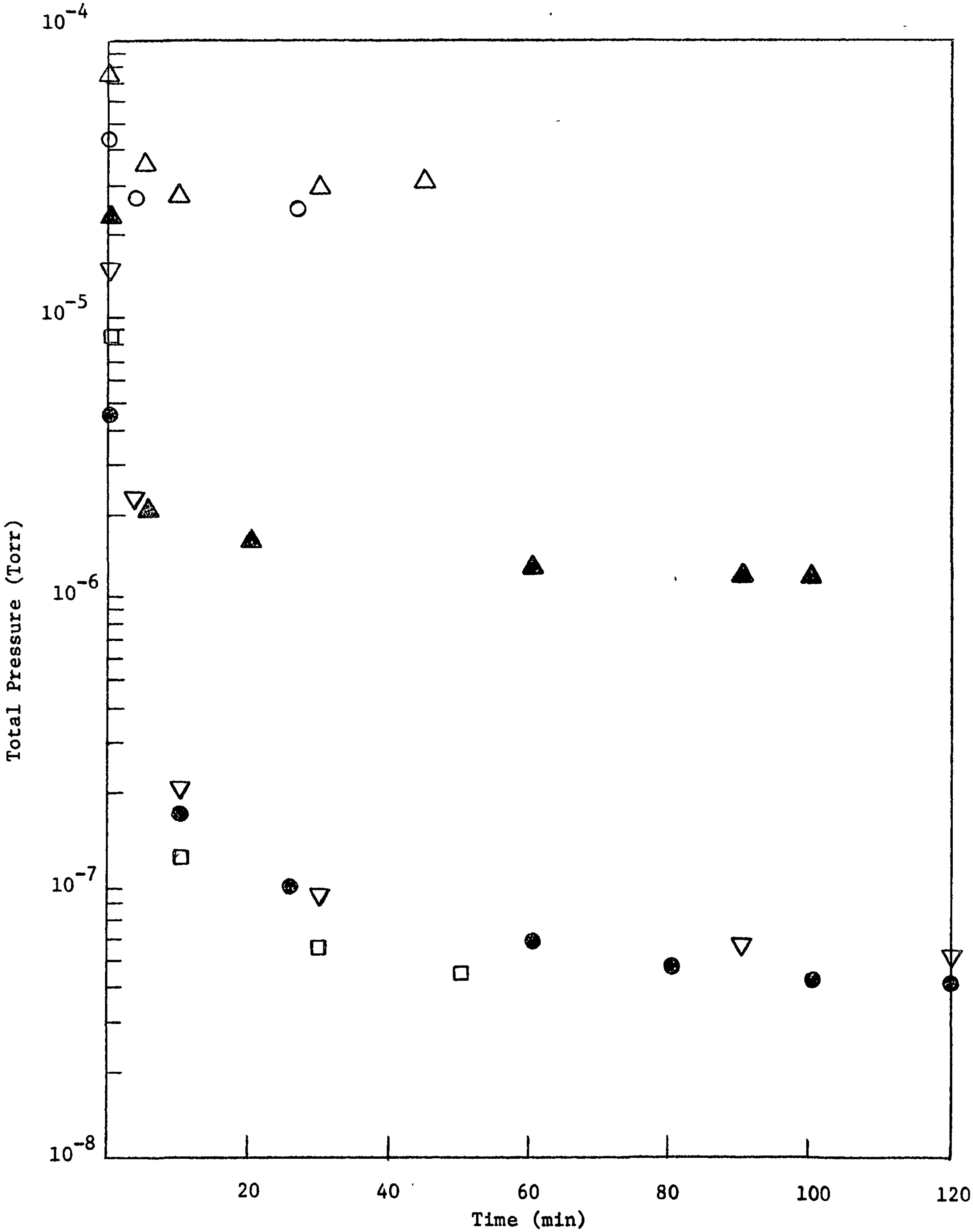

Figure 10. Variation of total pressure with time for six initial pressures as a result of surrounding the vessel with LN_2.